

# EARLY VALIDATION OF SENTINEL-2 L2A PROCESSOR AND PRODUCTS

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## ABSTRACT

Sentinel-2 is a constellation of two polar orbiting satellite units each one equipped with an optical imaging sensor MSI (Multi-Spectral Instrument). Sentinel-2A was launched on June 23, 2015 and Sentinel-2B will follow in 2017.

The Level-2A (L2A) processor Sen2Cor implemented for Sentinel-2 data provides a scene classification image, aerosol optical thickness (AOT) and water vapour (WV) maps and the Bottom-Of-Atmosphere (BOA) corrected reflectance product. First validation results of Sen2Cor scene classification showed an overall accuracy of 81%. AOT at 550 nm is estimated by Sen2Cor with uncertainty of 0.035 for cloudless images and locations with dense dark vegetation (DDV) pixels present in the image. Aerosol estimation fails if the image contains no DDV-pixels. Mean difference between Sen2Cor WV and ground-truth is 0.29 cm. Uncertainty of up to 0.04 was found for the BOA-reflectance product.

## 1. INTRODUCTION

The Copernicus programme is a European initiative for the implementation of information services dealing with environment and security, mainly based on observation data received from Earth Observation (EO) satellites. In the frame of this programme, ESA launched the Sentinel-2A optical imaging mission on 23th June 2015. Sentinel-2 delivers a new generation of optical data products designed to directly feed downstream services mainly related to land monitoring, emergency management and security.

To ensure the highest quality of service for the Sentinel-2 mission, ESA set up the Sentinel-2 Mission Performance Centre (MPC). MPC includes several Expert Support Laboratories (ESL). Telespazio France (TPZ-F) and German Aerospace Centre (DLR) have teamed up to ESL-L2A in order to provide the calibration and validation of the Level-2A processor Sen2Cor. First results of Sen2Cor validation performed by ESL-L2A are reported within this paper.

Validation datasets to be used for on-going L2A Cal/Val activities cover different land cover types, different atmospheric conditions and include different latitudes in order to cover various solar angles and seasons. However, the present study is still limited to a small dataset mainly from the southern hemisphere. First validation should be performed with up-to-date calibrated Level-1C data. Current L1C processing baseline started at end of November 2015 when sun elevation was very low in the Northern latitudes and partly outside the validity range of the look-up-table. Therefore analysis concentrated on test sites of the Southern Hemisphere. First reprocessed products over Europe from last summer could be included.

The paper starts providing some background to Sen2Cor. Validation results for cloud screening and scene classification, Aerosol Optical Thickness (AOT), Water Vapour (WV) and Bottom-Of-Atmosphere (BOA) reflectance products are provided in the following sections together with a short explanation of the validation approaches.

## 2. SEN2COR

Sen2Cor was implemented by Telespazio Germany, TPZ-F and DLR on behalf of ESA. Sen2Cor Level 2A

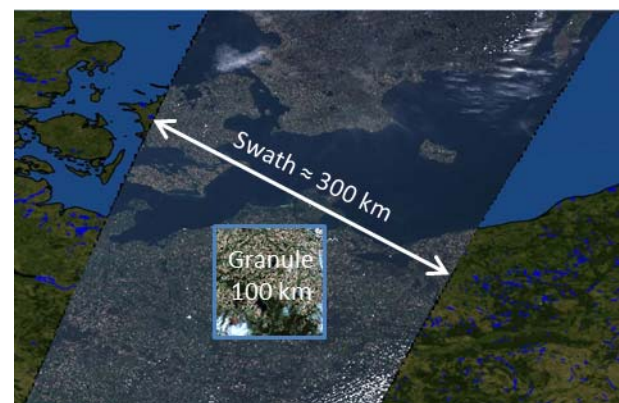


Figure 1. Relation of granule to swath of Sentinel-2.

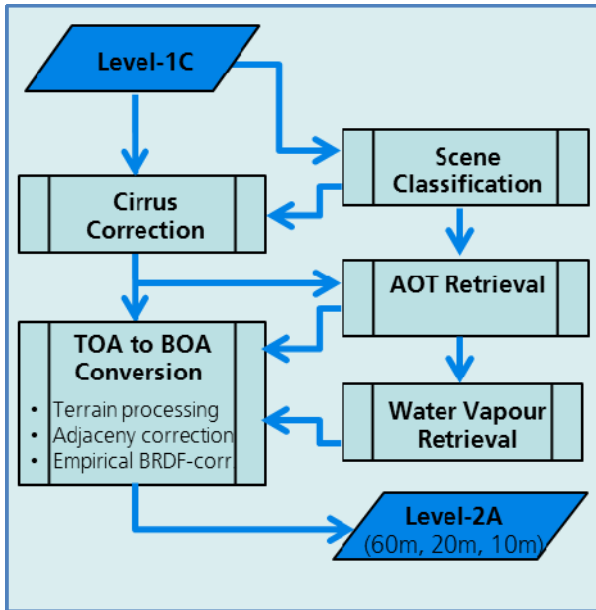


Figure 2. Sen2Cor processing scheme and products

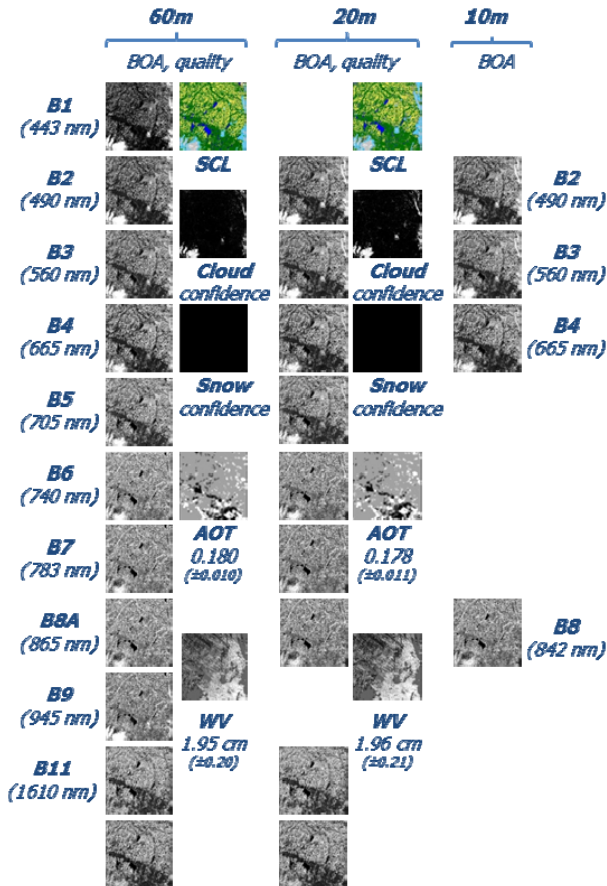


Figure 3. Sen2Cor outputs at different spatial resolution

processing is applied to granules of Top-Of-Atmosphere (TOA) Level 1C ortho-image reflectance products (Fig. 1). Processing starts with scene classification

followed by AOT and WV retrieval (Fig. 2). Last step is the TOA to BOA conversion. Sen2Cor has the option to activate a cirrus correction module. Sen2Cor L2A outputs are a scene classification (SCL) image, AOT and WV maps and the ortho-image BOA corrected reflectance product. Scene classification is generated together with Quality Indicators for cloud and snow probabilities. Sen2Cor outputs are provided for spatial resolutions 60m, 20m and 10m (Fig. 3).

Sen2Cor atmospheric correction is based on ATCOR algorithm [1] including a terrain correction, adjacency correction and an empirical BRDF-correction option. The implemented algorithm requires Dense Dark Vegetation (DDV)-pixels in the image for AOT-retrieval.

Sen2Cor can be configured through the L2A\_GIPP.xml file. Sen2Cor has the option for parallel processing of different granules. The number of processes to run at the same time can be set by the user or automatically determined by the processor. The user can process images using a Digital Elevation Model (DEM), which can be provided by the user in DTED format or downloaded automatically by the processor (SRTM in this latter case). When no DEM is used the mean elevation should be carefully set. There are 24 look-up-tables for Sen2Cor including rural and maritime aerosols for midlatitude summer and midlatitude winter atmosphere profiles. The ozone content is selected automatically by Sen2Cor if ECMWF auxiliary data are present in the L1C-input data.

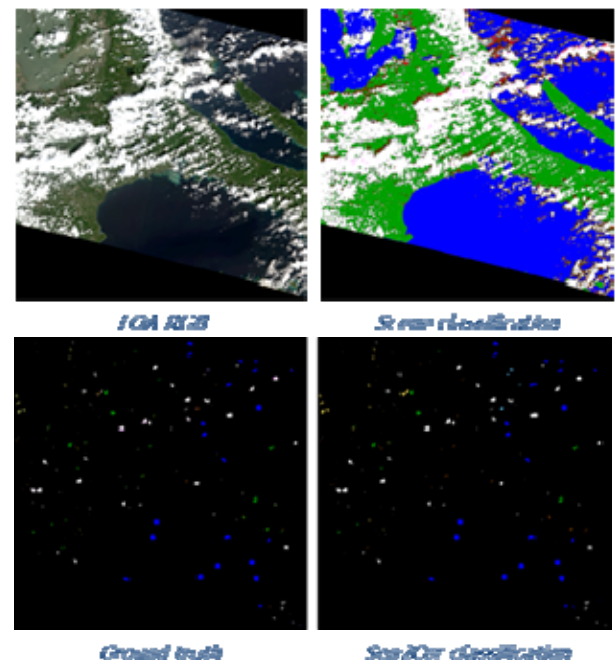


Figure 4. Validation example for Cloud Screening & Scene Classification. Top: TOA-RGB and L2A-scene classification image, Bottom left: Ground truth classification image and bottom right: Corresponding pixels from Sen2Cor classification image.

Table 1. Precision and Confusion matrix for classification validation example

	Pre- cision	Sen2cor class	Reference Class											
			(1)	(2+3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Sum	
Saturated or defective	0,11	(1)	2	0	0	0	5	11	0	0	0	0	18	
Dark area pixels & cloud shadows	0,47	(2+3)	29	7326	29	2161	1561	314	372	793	2988	0	15573	
Vegetation	0,64	(4)	4	8141	20668	2942	14	540	64	24	0	0	32397	
Bare soils	0,87	(5)	25	3	136	5179	11	429	82	110	0	0	5975	
Water	0,98	(6)	46	165	1	7	106908	206	179	419	783	0	108714	
Cloud low probability	0,11	(7)	7	957	173	5046	14	1069	1042	420	927	0	9655	
Cloud medium probability	0,38	(8)	0	69	24	433	1	1311	2003	1336	108	0	5285	
Cloud high probability	0,78	(9)	8	4	3	55	4	1683	15735	63821	12	0	81325	
Thin cirrus	0	(10)	0	0	0	0	4	0	0	0	0	0	4	
snow	0	(11)	0	84	0	0	0	0	54	8068	0	0	8206	
		Sum	121	16749	21034	15823	108522	5563	19531	74991	4818	0	267152	

### 3. VALIDATION OF CLOUD SCREENING & SCENE CLASSIFICATION

A granule of size 110km x 110km is used in each cloud screening and scene classification validation. As first step a reference dataset is built by stratified random sampling with a minimum of 50 samples per class. Then a user evaluates this reference data set sample by sample visual labelling. RGB band composition (bands 4, 3, 2), CIR band composition (band 8, 4, 3), spectrum, snow confidence and cloud confidence are displayed with marked current pixel to support the decision. The user can either label one pixel or an area containing pixels of the same class. All labelled pixels are then used for the creation of the reference image. The reference image is compared to the Sen2Cor classification image to compute the confusion matrix and precision of classification per class.

Validation example for one product is shown in Fig. 4 and Tab. 1. A total of 276152 pixels have been labelled in this example which corresponds to 0.89% of all

pixels of the image. Tab. 1 presents the precision of classification per class and the confusion matrix. This example yields an overall classification accuracy of 78%. Mean overall accuracy for all examples processed is  $(80 \pm 5) \%$ .

### 4. VALIDATION OF AOT AND WV PRODUCTS

The principle of validation of AOT and WV products is a direct comparison of Sen2Cor outputs with ground-truth from AERONET [2] sunphotometer measurements. For WV validation, the average Sen2Cor output over all soil and vegetation pixels within 9km x 9km area around sunphotometer location is computed. AOT validation includes also water pixels for the same area.

All L1C products for selected validation sites are automatically downloaded without regard to cloudiness of the acquisition. Therefore, the first analysis step is to exclude full cloudy scenes from analysis. Next after

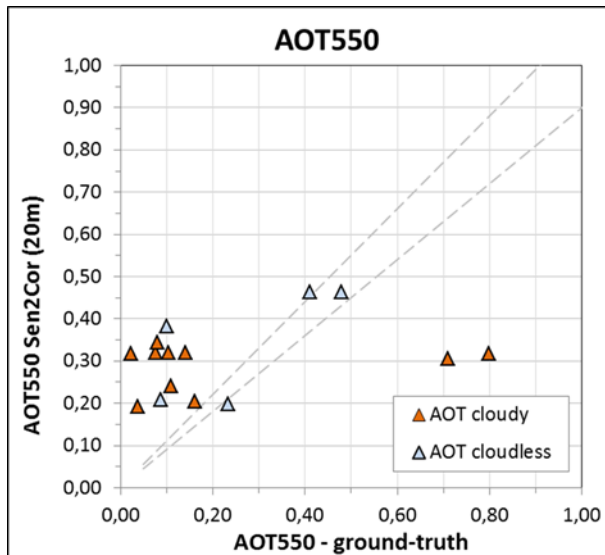


Figure 5. AOT-Validation, Direct comparison Sen2Cor<-> ground reference.

cloudiness check, the availability of AERONET data is checked for the selected S2-scenes. AERONET stations may be out of operation when instruments are removed for maintenance and calibration. AERONET data may be also not available for some acquisitions due to clouds at satellite overpass time. AOT at 550 nm and WV content are interpolated to Sentinel-2 overpass time after successful download of AERONET data.

L1C products were processed to L2A using the default Sen2Cor configuration (e.g. cirrus correction OFF) and with SRTM-DEM activated. A spatial subset of size 9km x 9km around sunphotometer location was extracted from L2A output. Scene classification provided the masks applied for the statistical computation. Mask for WV-validation includes all vegetation and bare soil/desert pixels. Mask for AOT-validation contains additionally all water pixels.

Table 2. Validation results for AOT@550nm (spatial resolution 20m)

. \ .	No. of samples	Min AOTdif	Mean AOTdif	rms AOTdif	Max AOTdif
<b>Cloudiness &lt;65%</b>					
Boreal	1	0,035	0,035		0,035
subtropical N	7	0,036	0,226	± 0,140	0,480
Tropical	3	0,016	0,158	± 0,215	0,405
Midlatitude S	3	0,122	0,222	± 0,088	0,282
<b>Total</b>	<b>14</b>	<b>0,016</b>	<b>0,197</b>	<b>± 0,142</b>	<b>0,480</b>
<b>Cloudiness &lt;5% and images with no DDV pixels excluded</b>					
Boreal	1	0,035	0,035		0,035
Tropical	2	0,016	0,034	± 0,026	0,053
<b>Total</b>	<b>3</b>	<b>0,035</b>	<b>0,035</b>	<b>± 0,019</b>	<b>0,053</b>

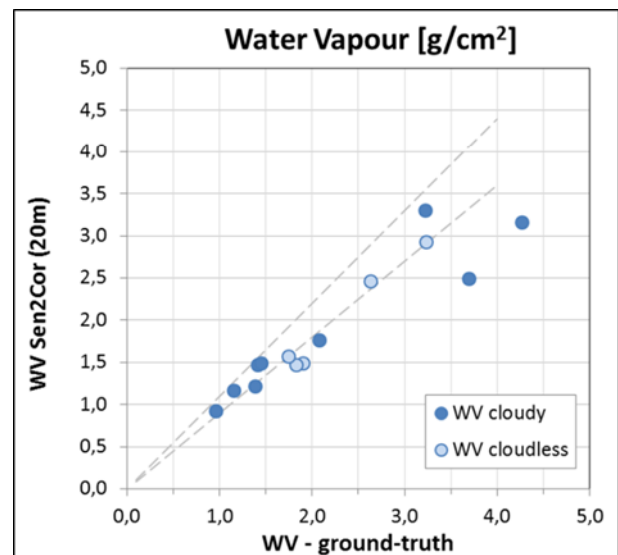


Figure 6. WV-Validation, Direct comparison Sen2Cor<-> ground reference.

Results for processing with 60 m, 20 m or 10 m spatial resolution give consistent results. AOT validation results are shown in Fig. 5 and Tab. 2. Sen2Cor produced some very good AOT estimation samples, however also some with large differences between Sen2Cor and ground truth. Most of bad samples suffer from lack of DDV-pixels, which are necessary for the AOT-retrieval algorithm implemented in Sen2Cor. AOT is set to a default value of around 0.30 when there are not sufficient DDV-pixels in the image. Limiting the statistical analysis to samples with sufficient DDV-pixels in the image and with cloudiness less than 5% gives results in accordance with experience from other validation studies. Validation of AOT will be continued to get statistically more relevant results, most of all

Table 3. Validation results for WV

. \ .	No. of samples	Min Wvdif	Mean Wvdif	Rms Wvdif	Max Wvdif
<b>Cloudiness &lt;65%</b>					
Boreal	1	0,176	0,176		0,176
subtropical N	7	0,016	0,258	±0,411	1,116
Tropical	3	0,317	0,365	±0,052	0,420
Midlatitude S	3	0,172	0,222	±0,079	0,313
<b>Total</b>	<b>14</b>	<b>0,016</b>	<b>0,267</b>	<b>±0,287</b>	<b>1,116</b>
<b>Cloudiness &lt;5%</b>					
Boreal	1	0,176	0,176		0,176
Tropical	2	0,358	0,389	± 0,044	0,420
Midlatitude S	2	0,181	0,247	± 0,094	0,313
<b>Total</b>	<b>5</b>	<b>0,176</b>	<b>0,290</b>	<b>± 0,108</b>	<b>0,420</b>



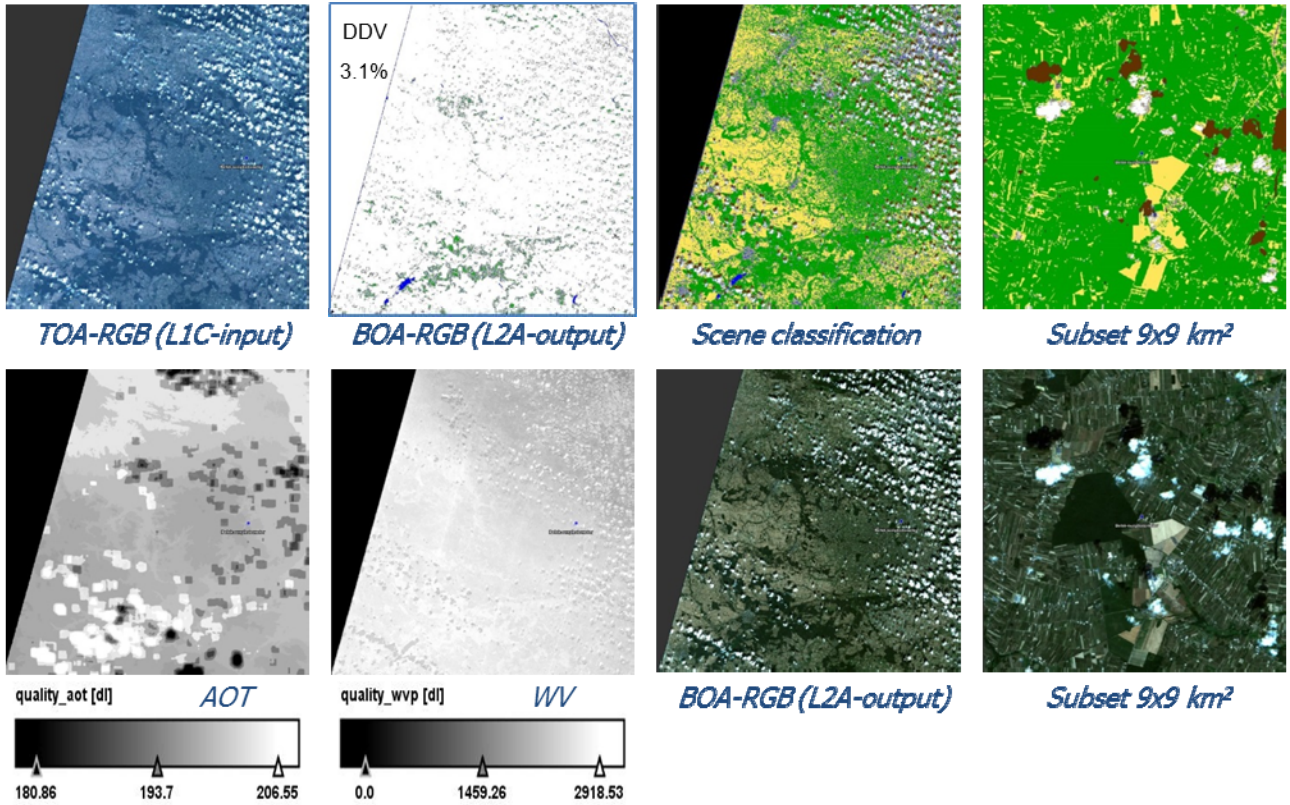


Figure 7. Example processing Sentinel-2 data

including more test sites with DDV-pixels in the images. Present validation results for Sen2Cor are in-line with validation results for other atmospheric correction algorithms found in the literature [3].

WV retrieval (Fig. 6, Tab. 3) gives better results than AOT. Retrieval accuracy is less influenced by cloud cover and missing DDV-pixels. There seems to be a hint at underestimation of higher WV content by Sen2Cor.

## 5. VALIDATION OF BOA PRODUCT

The image analysis for the validation of the BOA reflectance product works the same way as for the AOT and WV product validation with the extraction of the 9km x 9km subset. The reference BOA reflectance is generated by running the atmospheric correction with a constant AOT value equal to the AOT value measured by the AERONET instrument.

A recently reprocessed L1C-product for test site Belsk was selected for demonstration of the atmospheric correction results typical for locations with sufficient DDV-pixels. Fig. 7 gives a first impression of the Sen2Cor processor performance. The L2A-product is clearly improved in comparison with the L1C-product. Scene classification agrees with the expectation for this site returning a lot of vegetated and soil pixels. Zooming

into the 9km x 9km subset shows that cloud shadows are correctly classified. There is no mis-classification visible. DDV-pixels are distributed over the full image. The granule contains 3.1% DDV-pixels, which is sufficient for an accurate estimation of aerosol amount. Variation of AOT550 and WV is small across the

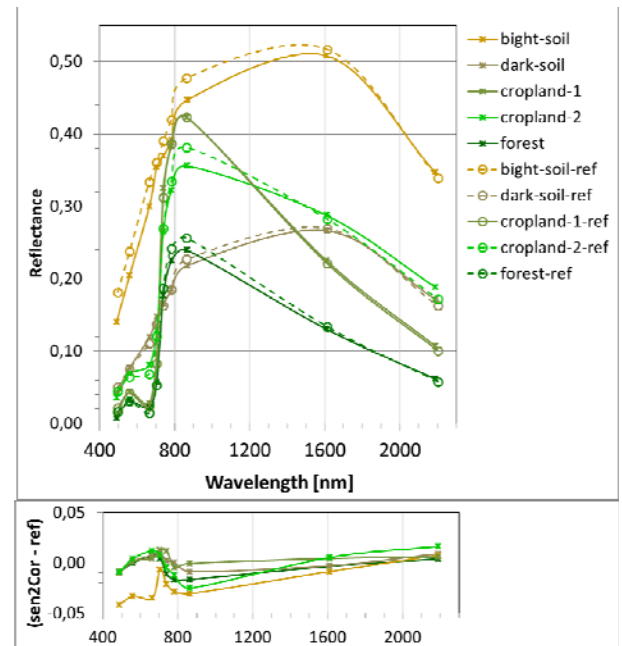


Figure 8. Example spectra

granule. Both AOT and WV averages across the subset are in good agreement with the reference value obtained from AERONET. Sen2Cor provides an AOT value at 550 nm of 0.20 with a reference value from AERONET of 0.23. WV is estimated from Sen2Cor with a value of 2.46 cm with a reference value from AERONET of 2.63 cm. Several example spectra were extracted in the reference image and in the image to validate (Fig. 8). Example spectra for dark and bright soil, for forest and for different other vegetated locations show the expected spectral dependency and agree between reference and the spectra to be validated. A difference up to 0.04 in surface reflectance between Sen2Cor-processing and reference had been found, leading to a Normalized Density Vegetation Index (NDVI) uncertainty up to 0.06 (Tab. 4). Validation of BOA-reflectance will be continued to get statistically more relevant results, most of all including more test sites with DDV-pixels in the images. Validation will be continued also with analysis of campaigns providing fiducial reference measurements performed in 2015.

Table 4. Example NDVI ;  $(R865-R665)/(R865+R665)$

NDVI	bight-soil	dark-soil	Crop-land-1	Crop-land-2	forest
Sen2Cor	0,20	0,29	0,88	0,63	0,84
reference	0,18	0,34	0,89	0,69	0,89
Sen2Cor-reference	0,02	-0,05	-0,02	-0,06	-0,06

## 6. OUTCOME

The scene classification produced by Sen2Cor works correctly. Mean overall accuracy of processed validation examples is  $((80 \pm 5) \%)$ . AOT retrieval uncertainty of about 0.03 is typical for cloudless images and locations with DDV pixels present in the image. Aerosol estimation fails and a default AOT value is then used, if there are no DDV-pixels in the image. Sen2Cor WV estimation agrees better with ground-truth than AOT. Results are less influenced by cloud cover and missing DDV-pixels. Atmospheric correction works accurate, if DDV pixels exist in the granule and AOT can be estimated. Sen2Cor produces reasonable spectra for different surface types with amount of reflectance difference between Sen2Cor processing and reference

up to 0.04. This reflectance uncertainty leads to an NDVI uncertainty up to 0.06. These early validation results were obtained using only a small dataset. Validation will be continued using a larger dataset covering the full globe and all seasons.

## 7. CREDITS

The authors thank the PI investigators and their staff for establishing and maintaining the AERONET sites used in this investigation.

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